Use of the International Space Station for Observations Beneficial to International Polar Year 2007-2008

Donald Pettit
NASA JSC
Code CB
Houston, TX 77058

Abstract

This paper describes salient characteristics of the International Space Station (ISS) relevant to International Polar Year (IPY) 2007-2008 for observations from the ISS. It provides guidance for scientists participating in IPY research who are interested in requesting imagery of polar regions from the ISS. Examples of prior polar imagery are presented to help IPY scientists understand the capabilities of astronauts' polar observations. Description of the NASA process for requesting and retrieving imagery are presented as well as background information on the ISS camera systems. A short tutorial on the ISS orbital effects on Earth observations is presented as background information, realizing that NASA will do all the necessary orbital calculations for an IPY request.

1. Introduction

A proposal was accepted by the IPY committee for the use of the ISS as a platform to augment observations of polar phenomena from scientists on ground sites, airplanes, and from other orbiting assets during the polar campaigns planned for 2007-2008. The proposal, with activity ID #78 under Bi-Polar Expression of Intent (EoI), can be viewed at:
http://www.ipy.org/development/eoi/proposal-details.php?id=78

The NASA Space Operations Directorate (in charge of all NASA human spaceflight) through the Space Station Program Office (in charge of ISS) is supporting this activity with participation by the ISS External Integration Office (in charge of payloads on ISS) and the ISS Program Scientist's Office (in charge of ISS science). The scientific imaging objectives for IPY will be coordinated by the Crew Earth Observation (CEO) project (in charge of implementing the IPY-ISS activities). CEO normally uplinks daily imagery targets of geographic significance and the ISS crews are usually able to fill them. The CEO program will work with IPY scientists to add imagery targets of significance to IPY to the daily uplink. This represents a way to use an existing human spaceflight program to augment IPY. Essentially, the observation capabilities of the ISS are made available to the IPY scientists for only the effort of communicating their imagery needs to NASA-CEO.

More information on IPY can be found at the following web sites:
http://www.ipy.org/

http://www.us-ipy.org/
http://www.us-ipy.gov

Why use the International Space Station for Polar Observations

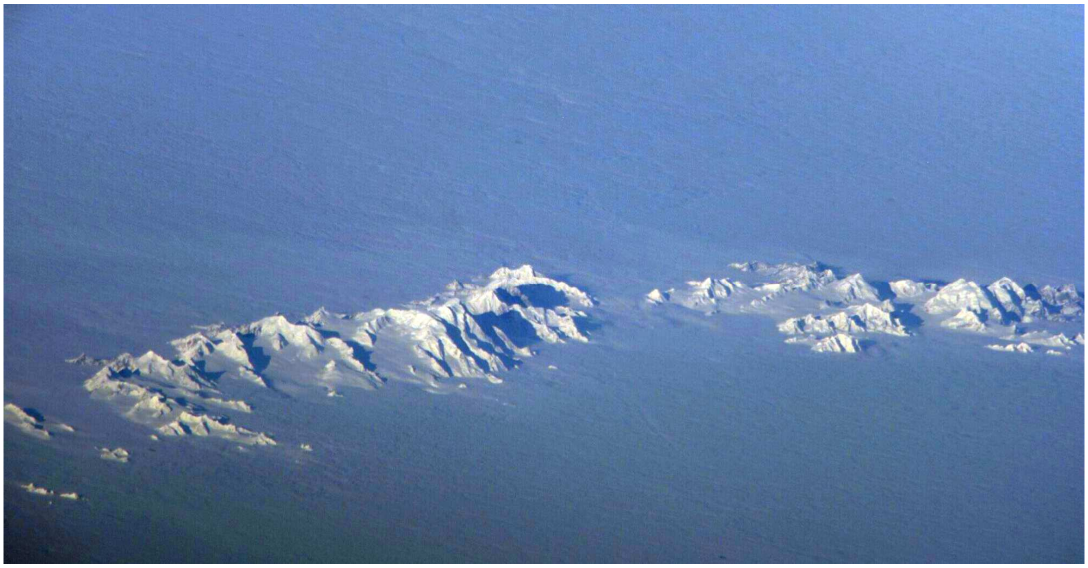
The orbit of the ISS takes it to north and south latitudes of 51.6 degrees at altitudes of about 400 km. From this altitude the diameter of the astronaut's horizon circle is about 40 degrees of latitude, or 4400 km. From this vantage point, the ISS is a platform that allows observations of artic and Antarctic phenomena on a length scale of about half a continent. While the astronaut observations are constrained in several ways (see discussion in following sections), the ISS observations can be used to compliment ground site observations and satellite data that can be synchronized in both space and time with on-going ground campaigns. Observations from the ISS offer an above-the-cloud vantage point for observations including wide angle oblique views, sun-glint textures, day-night terminator lighting, seasonal variations, and perhaps most important, human guided observations that can fall outside the purview of pre-programmed field-of-view instrumentation. Observations can be made the year around and are not limited to the typical polar summer ground site seasons. The ISS offers a platform particularly suited for Antarctic atmospheric observations since it gives repeated coverage circumscribing the continent every day where cloud cover and the general lack of observation sites limits routine ground observations over long periods of time.

2. Example Uses of the International Space Station

One must keep in mind that observations from ISS are intended to augment field observations and data made from ground sites, ships, balloons, sounding rockets, airplanes, or satellite platforms. These other sites will have rigorously calibrated instruments that exceed the current orbital capabilities on ISS. The cameras on ISS are well characterized (details in following section) but not calibrated and as such, the data should not be used beyond its rigor. Presented below are a few examples of polar ISS imagery collected during previous expeditions to be used as a means to incite further ideas for IPY-ISS collaborations. Image numbers are referenced, allowing access to the images for downloading from http://eol.jsc.nasa.gov , together with the associated meta-data for each image.

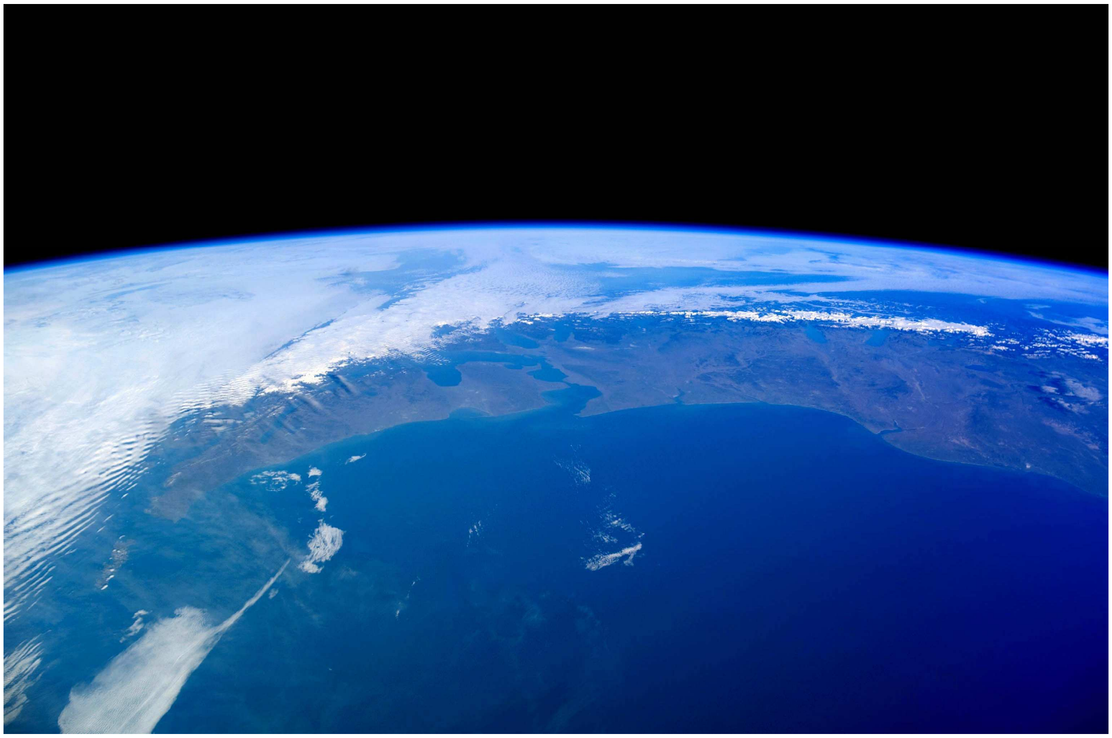
General Antarctic Imagery

Shown below are a few examples of ISS imagery of day time subjects in the Antarctic region.



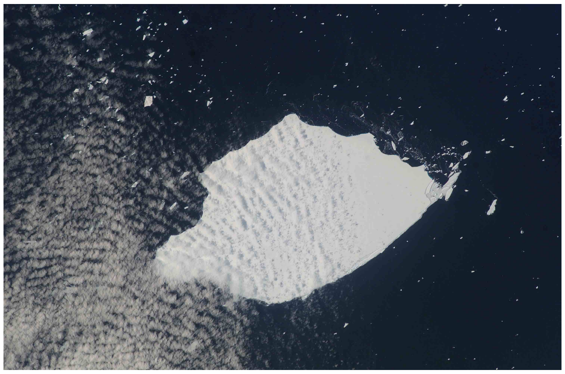
Mountains on the Antarctic Peninsula above cloud cover taken from ISS at south 50.4 degrees latitude and west 54.8 degrees longitude. Image was taken on 8/25/05 by Expedition 11 looking due south with 800 mm telephoto lens. The image center is about at south 64 degrees latitude.

Sea ice located off shore from the Antarctic Peninsula taken from ISS at south 51.6 degrees latitude and west 64.1 degrees longitude. Image was taken on 8/30/05 by Expedition 11 looking due south with 800 mm telephoto lens. The image center is about at south 63 degrees latitude. Image ISS011-E-12235.

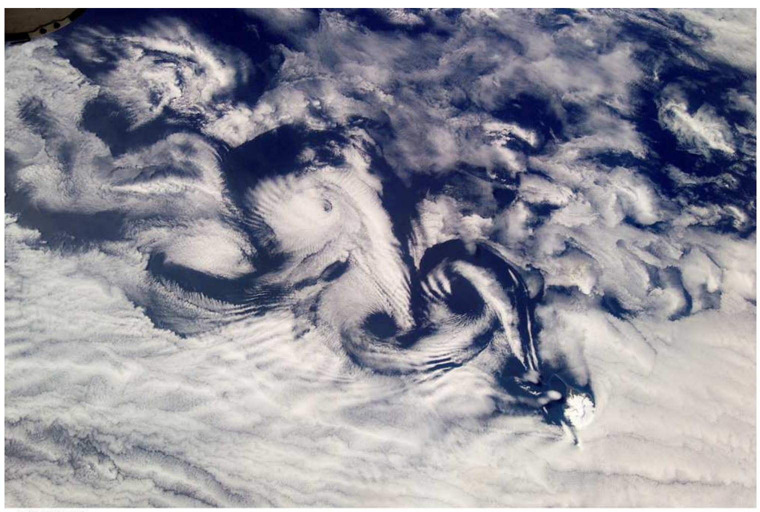


Wide angle oblique showing the tip of South America while ISS was at south 51.6 degrees latitude and west 40 degrees longitude near South Georgia Island. Image was taken in February 2003 by Expedition 6 looking westward with a 14 mm lens.

South Georgia Island taken with 180 mm lens March 13, 2003 by Expedition 6. Image ISS006-E-38081.



Giant icebergs near South Georgia Island taken with 180 mm lens (left, image ISS006-E-41786) and 85 mm lens (right, image ISS006-E-41384) on Mar 29, 2003 by Expedition 6. The icebergs are located in the southern Atlantic Ocean at roughly 51^{o} S and between 32 and 42 ^{o}W.

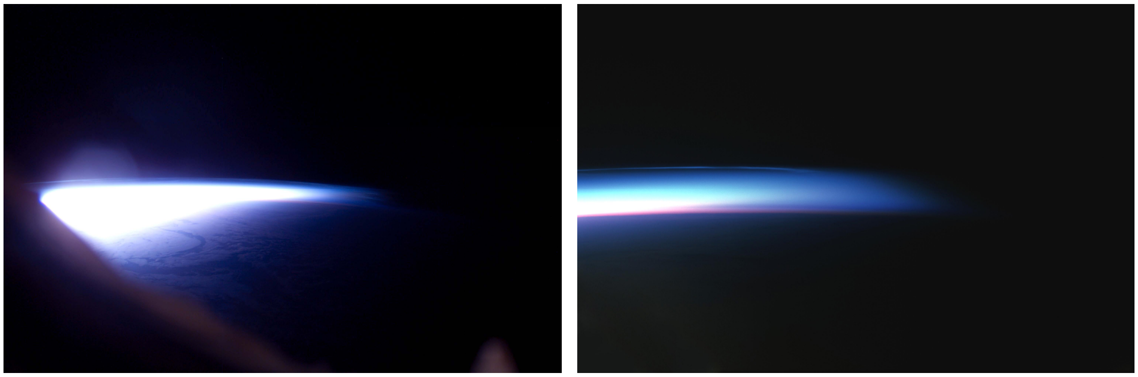


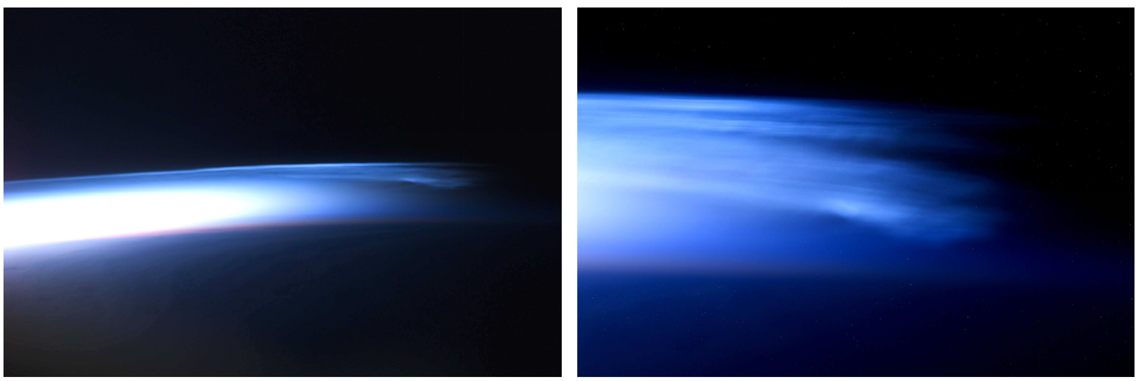
Left: Wide image (28 mm lens) of Heard Island with lee-side cloud formations of Von Karmen vortices (image ISS005-E-21799). Right: Heard Island detail view (800 mm lens) taken by Exp 5 on November 29, 2002 (image ISS005-E-21803). Heard Island is at 53 ^{o} S and east 74 ^{o} E.

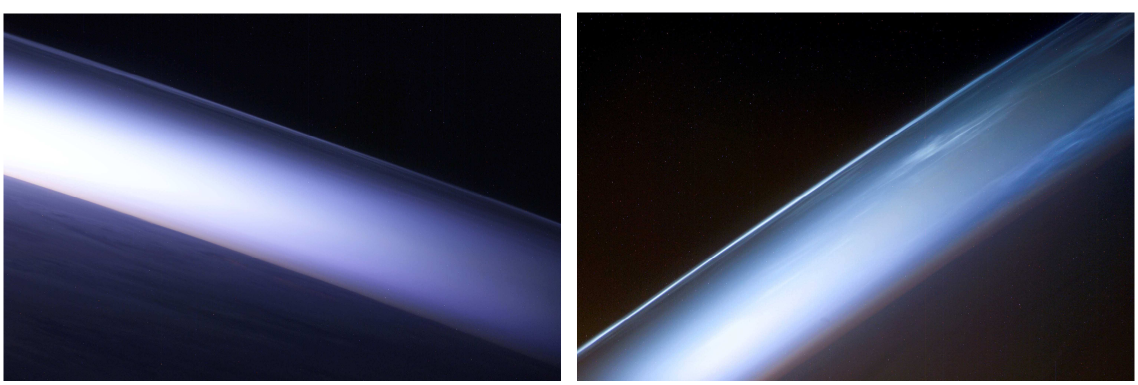

Oblique view of South Shetland Island taken with 180 mm lens on 11/10/03 by Expedition 8 from ISS at south 51 degrees latitude and west 54.5 degrees longitude. Center image is about south 65 degrees latitude.

<u>Polar Mesospheric Clouds (PMC)</u>

The CEO database includes a number Polar Mesospheric Clouds (PMC) images (also called Noctilucent Clouds) taken across the terminator, during daytime or during nighttime, with wide angle to telephoto lenses. PMC are typically a thin layer of ice crystals about 2-4 km thick at about 82 to 84 km altitudes. Optimum viewing geometry for observing PMC is across the day-night terminator where the clouds are illuminated by sunlight but seen with a black night sky. In these orbital images, the top thin line is this cloud layer seen on edge. Since the cloud geometry is a thin spherical shell concentric to Earth's surface, the PMC seen nearest the horizon are actually the most distant.

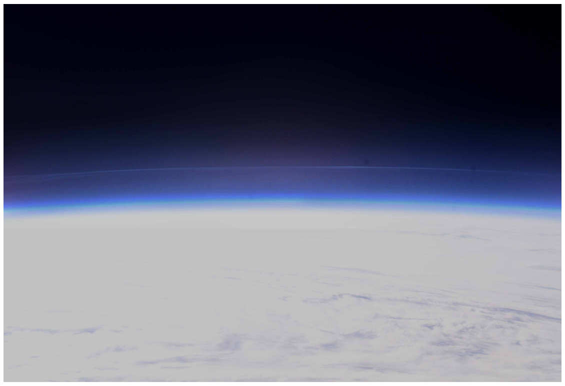
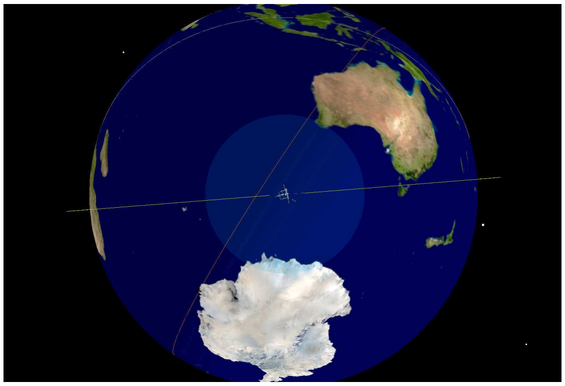

PMC images at terminator edge (left) with 28 mm lens showing feathery structures and image (right) with 85 mm lens taken in southern hemisphere in January 2003 by Expedition 6. The atmospheric brightness exceeds the 12 bit dynamic range of the camera CCD array so exposures need to be chosen to show the subjects of interest, which in this case, are the low intensity PMC thus the brighter atmosphere is over exposed.


PMC images at terminator edge (left) showing feathery structures with 85 mm lens and image (right) with 400 mm lens taken in southern hemisphere in January 2003 by Expedition 6.

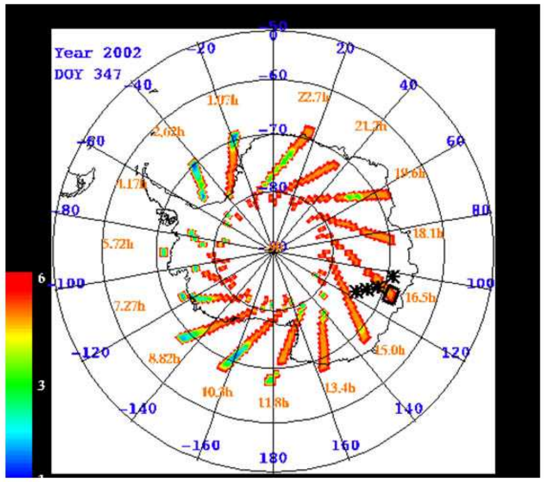

PMC images using 180 mm lens (left and right) taken in northern hemisphere in June 2006 by Expedition 13. Northern PMC are significantly brighter than those in the southern hemisphere and lend themselves to shorter exposures with longer focal length lenses and a dynamic range that is easier to capture by the 12 bit CCD pixels.

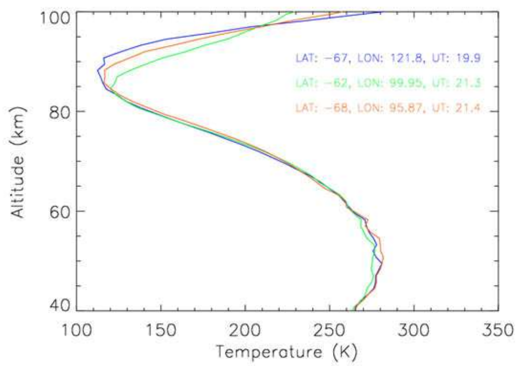
 

PMC images using 400mm lens (left and right) taken in northern hemisphere in July 2003 by Expedition 7. For PMC observations, oblique wide angle images are good to record the spatial extent while medium to long telephoto images are good to record structure.

PMC image in daylight (left) looking towards Davis region, Antarctica with 58 mm lens December 13, 2002 by Expedition 6. ISS was at south 51 degrees latitude and east 111 degrees longitude with image taken while looking due south. Reconstruction of viewing geometry (right) showing ISS with horizon circle (light blue), orbit path (yellow), and day-night terminator (red line with daylight on right side).

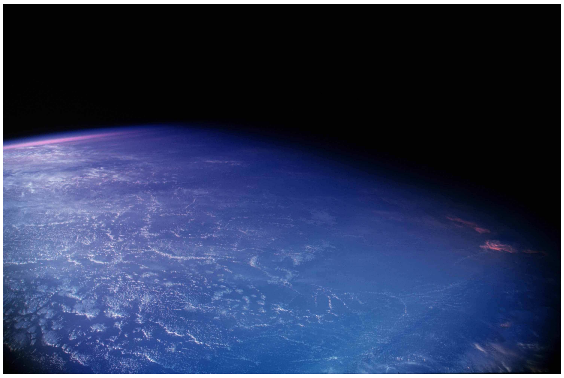
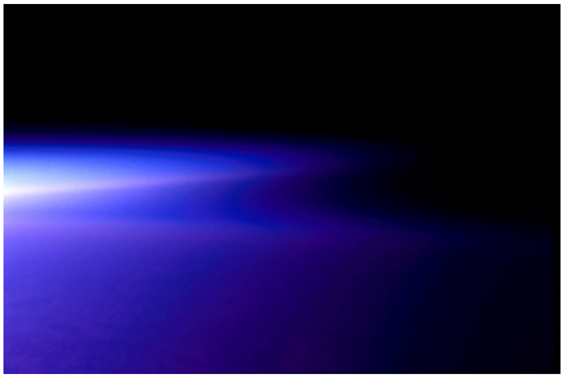




Co-located observations are shown for PMC from satellites and ISS for the previous Davis image. SNOE satellite data from Antarctic passes is drawn (top) as over-lapping colored squares showing PMC scattered intensity according to colored scale on left with orbit pass times in GMT hours for December 13, 2002. The bright orange rectangles show a strong scattered light intensity from PMC and show the PMC location strongest on the Davis side of the continent. The black rectangular box at 16.5 hours GMT is the ISS image field of view from the above Davis PMC image. The black asterisks are the co-location of UV scattering measurements from NOAA-16 and NOAA-17 SBUV/2 instruments which also show a positive detection of PMC. The temperature plot (bottom) shows co-located temperature measurements for three passes from the TIMED satellite using the SABER instrument showing that at the typical altitude of PMC (83 km) the temperatures were between 110 to 120 degrees K. This data was reconstructed after the observations were made (from Thomas G.E. et.al. AGU, San Francisco, Dec. 2004). With advanced planning, truly synchronized observations for IPY are possible and could prove more valuable than uncoordinated efforts. An Australian team was making ground-based LIDAR measurements of PMC at Davis during this time period, however, the thick cloud cover that day prevented LIDAR observations.

Day-Night Terminator

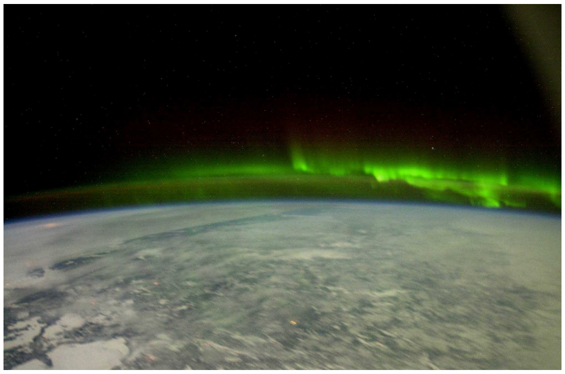
Shown below are two examples of day-night terminator views taken from ISS during Expedition 6.

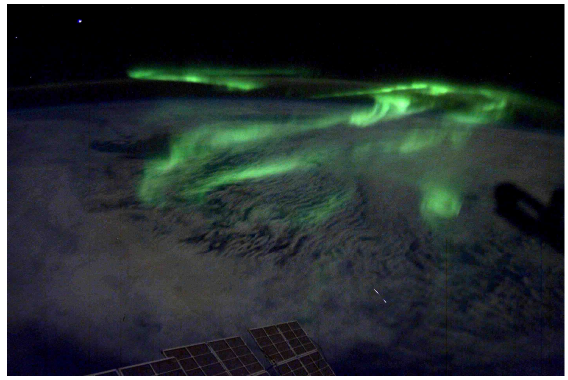
Examples of day-night terminator images where (left) was taken from daylight looking towards nighttime with a 28 mm lens and (right) was taken along the terminator axis with a 180 mm lens showing the geometric projection of a solar ray and the subsequent shadow due to the curvature of Earth.

Aurora

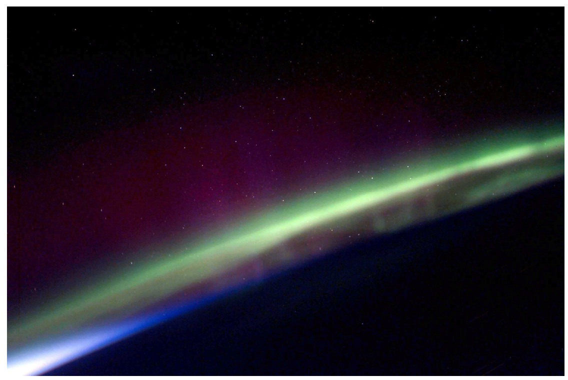
The real value of aurora imagery from ISS is the ability to observe spatial and temporal structure on the length scale of half a continent and be able to do this without the obscuration of cloud cover. This compliments observations from the calibrated instrumentation from ground sites, airplanes, rockets, and satellites which all have different observational length scales. The orbital altitude of ISS (400 km) is typically above the green 557 nanometer (nm) atomic oxygen emissions (100 to 200 km) and at the nominal altitude of the red 630 nm emissions (300 to 600 km), thus, spatial separations of these two distinct layers can sometimes be made simply by looking out ISS-nadir and ISS port/starboard windows. ISS can view aurora across the day-night terminator making possible observations of sunlit aurora and resonance scattering of sunlight. Below are a number of images that illustrate these possibilities from Expedition 6.

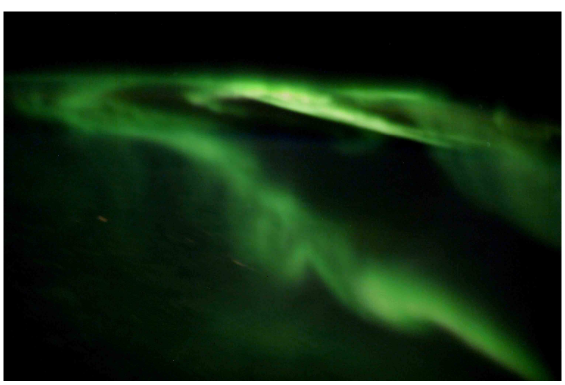
Aurora images showing large scale structures (left, ISS006-E-51530) with 58 mm lens and (right, ISS006-E-51537) with 28 mm lens over northern Canada in January 2003.

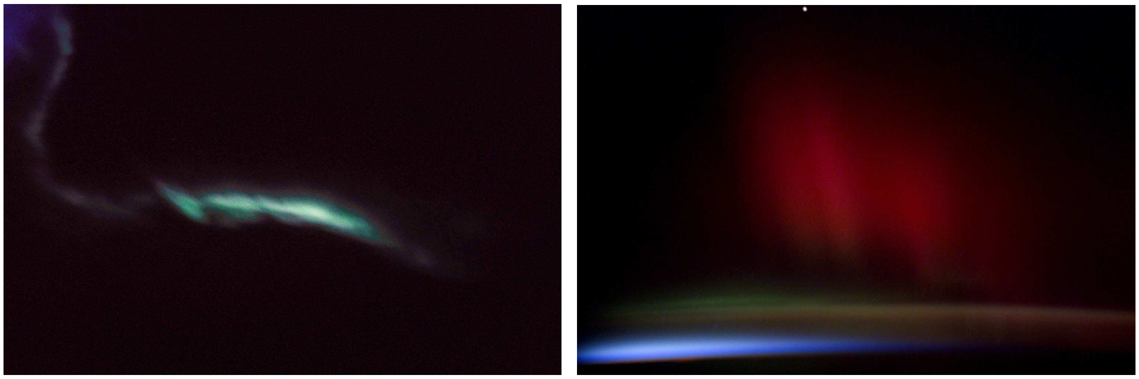
Aurora images showing large scale structure (left, ISS006-E-51542) with 28 mm lens over northern Canada with the Manicouagan impact crater visible and (right, ISS006-E-46278) over southern Australia with 58 mm lens showing curtain structures.

Aurora images taken March 31, 2003 with 58 mm lens near the terminator showing aurora extending over the daylight zone with some blue emissions due to solar resonance scattering from nitrogen atoms. (ISS006-E-41711, left and ISS006-E-41695, right).




Aurora images taken Jan 22 2003 (left, ISS006-E-21398) and Feb. 16, 2003 (right, ISS006-E-28957) with 58 mm lens showing green emissions from curtain structures while the ISS flies over the top.

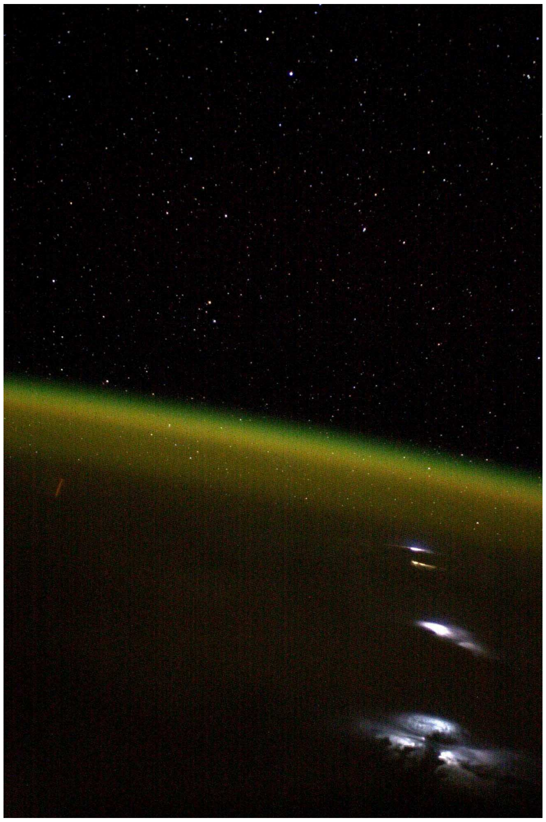


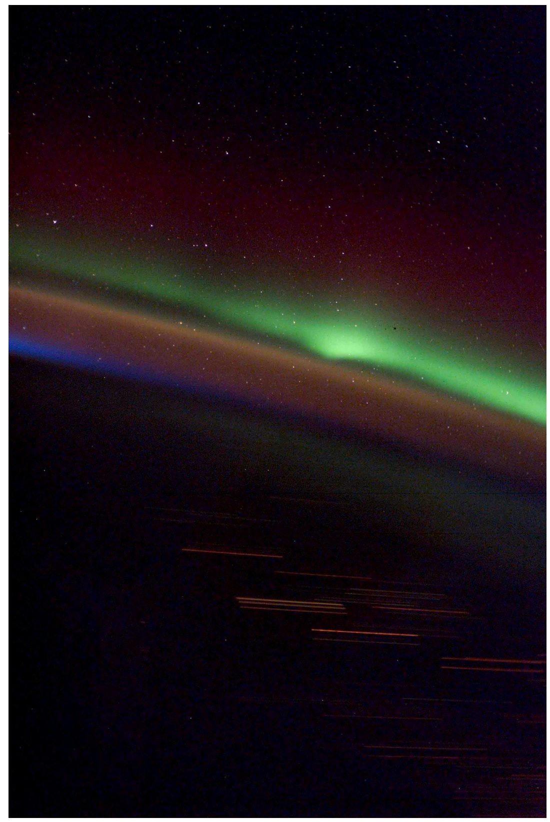
Nadir view (left) of aurora curtain taken with 58 mm lens as ISS flies over the top showing a spatial separation of green and red oxygen emission lines. Port view (right, ISS006-E-21591) of red aurora emissions at nominally the same altitude of ISS taken with 58 mm lens over northern Canada.

Synchronized aurora imagery from ISS and Turku Finland on March 31, 2003 by Expedition 6 and Pekka Parviainen. The ISS was at 51 ^{o} N latitude and 22 ^{o} E longitude near Warszawa Poland and image was taken (top ISS006-E-42492) viewing due north towards Turku Finland with a 28 mm lens viewing latitudes well above 60 degrees. City lights are seen as smudges in these time exposures with Stockholm Sweden seen as large spot in lower left, Turku is center brighter spot, and Helsinki is bright spot to it's right. Images from Turku were with 14 mm (bottom left) and 28 mm (bottom right) lenses and pointing due north towards the aurora activity. Imagery from ISS and ground was synchronized by prior agreement where each party took an exposure at the secondhand positions of 12:00 and 6:00 O'clock on GMT for the duration of the pass which lasted from about 20:46 to 20:53 GMT. These particular images were taken at 20:48:30 GMT. Unfortunately, the aurora display for this pass was relatively weak without strong structure but does serve to illustrate how synchronized imagery from ISS and ground sites for aurora can give collaborative information on widely varying length scales (Turku images copyright and courtesy of Pekka Parviainen).

Atmospheric Airglow

Shown below are two examples of atmospheric airglow taken from ISS during Expedition 6 with XPOP (solar inertial) attitude. This attitude allows for pin point star fields because it is nearly indistinguishable from a stellar inertial attitude over the time of exposure.



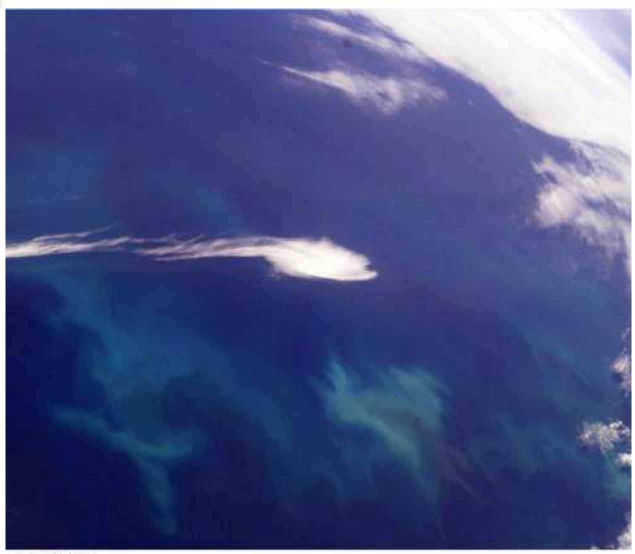


Atmospheric airglow (left, ISS006-E-48197) taken during the middle of orbital night showing the green 557 nm emissions from atomic oxygen over the atmosphere visual height of about 100 km. Star fields can be seen through the atmosphere as well as a few lightening flashes over the Earth. Atmospheric airglow (right) taken near the day-night terminator showing emissions from Sodium and OH due to resonance scattering from sunlight giving a red-orange airglow instead of green. A small wedge of blue is visible from the terminator as are aurora emissions in the green at 557 nm and red at 630 nm above the atmospheric airglow. The atmospheric visual height as seen from orbit is about 100 km. Green aurora emissions are typically 100 to 200 km and the red emissions are typically 300 to 600 km. City lights on Earth make streaks during the 15 second exposure at ISO 400 with a 58 mm f 1.2 lens.

Plankton Blooms

Large scale ocean patterns can be readily observed from orbit. Plankton blooms in polar regions are one example of such patterns and are illustrated below. Astronauts have tracked individual blooms for several days at a time, and observing the large scale spatial extent of their occurrence is possible from ISS imagery. Planned ISS observations also provide the potential for synchronized observations with unmanned satellites tracking ocean color and chloroform signatures, or planned research ship transects.

ISS008E12544



ISS008E12609

Two images of plankton blooms in the southern oceans taken by Expedition 8. The top image (ISS008-E-12544) shows an ice flow breaking apart and surrounded by smaller icebergs, amidst a large plankton bloom. The image is centered at 51.5 ^{o}S and 39 ^{o}W and taken on Jan 22, 2004 with a 50 mm lens. The bottom image (ISS008-E-12609) shows a colorful plankton bloom near Tierra del Fuego, taken on Jan 23, 2004. The spacecraft position was at 49.6 ^{o}S and 65 ^{o}W, looking to the southwest using a 50mm lens. Plankton blooms in the southern and northern oceans are commonly observed in the spring and summer months.

Volcanic Eruptions

Volcanic eruptions are spectacular from orbit, particularly from oblique angle views and offer additional large scale information about the impacts on the surrounding geography, particularly in remote polar regions where access is limited.

Eruption of Cleveland volcano in the Aleutian Islands at 52.8 ^{o}N and 170 ^{o}W taken by Expedition 13. While the Aleutian Islands are fairly well studied and instrumented, many volcanoes in remote polar regions are not monitored as closely as more accessible volcanic chains. This image, ISS013-E-24184, was taken May 23 2006 with an 800 mm lens.

3. Ground Operations in Support of IPY

This section provides details of how an IPY researcher can request an observation and how to retrieve the imagery afterwards. Most of the effort for obtaining IPY imagery from ISS is done by NASA ground support operations through CEO and the ISS crew. In Section 5 of this report is a short tutorial on how the ISS orbit affects Earth observations along with links to programs for calculating orbital path predictions. This is given as background information to IPY researches so that they can better understand the issues in coordinating imagery for a specific ground site at a specific time. IPY researches do not need to make these calculations when submitting a request. NASA CEO will take the information given on the web-based request form and make all the necessary calculations.

Image Requests

NASA's Image Science & Analysis Group (ISAG) at the NASA Johnson Space Center is tasked with ground planning and operations for the Crew Earth Observations (CEO). Their activities include receiving requests for Earth imaging for IPY, vetting requests against ISS orbital parameters and assembling a daily Earth observations task list for the crew using the most current spacecraft orbital elements.

CEO maintains a public website that includes an imagery request form. IPY investigators may fill out and submit this form for polar observations. This form will request pertinent information to facilitate planning and enhance success of image acquisition. Important information will include specific location of requested imagery and particular features of interest, requested start and stop times/dates, imaging frequency, preferred field-of-view (focal length lens), and any other special considerations (e.g. lighting constraints). This information is important for the CEO staff to appropriately plan data collection and communicate it to the crew.

IPY image request forms can be found at: http://eol.jsc.nasa.gov/ipy . This web page also provides links to the status of image requests, and other information for IPY scientists.

Image Data Archival and Distribution

IPY requested imagery taken with digital still cameras will be downlinked and cataloged with brief visual descriptions and merged with all of the metadata (time, spacecraft nadir location, image center point, solar angles, and other data. See table below). The cataloged imagery and metadata will be assimilated into the CEO database of astronaut photography of Earth.

All IPY still images will be made public on NASA CEO website on a timely basis. There will be a special subset web page from the CEO general database for all IPY imagery. Data availability will not be immediate. It is expected from prior experience that IPY images will be downlinked, identified, archived, and made public on the CEO website within about two to three weeks. There are several operational steps between imagery acquisition by a crew member on the ISS and data retrieval by the PI.

1) Images taken by crew members must be read from the camera flash memory together with the associated camera files on an ISS laptop for downlink to the ground. The availability of KU-band, high data rate downlink from ISS to the ground is not always available and may take a day or two.
2) Each image file is labeled and processed by NASA from the compressed downlink files into readable formats.
3) The data files are filtered by CEO scientists for IPY requests.
4) Each IPY image is cataloged with appropriate meta data and assimilated into the CEO database for public release.

General information on how to use the CEO archives can be found at: http://eol.jsc.nasa.gov/Info/

The CEO general imagery database (which includes all IPY images as well as all Earth observation images) can be found at:

http://eol.jsc.nasa.gov/sseop/sql.htm

The IPY image subset database can be found at:
http://eol.jsc.nasa.gov/scripts/IPY/ListRequests.pl

From either of these imagery databases, low resolution (about 100KB files) and high resolution (about 1.2MB files) are available for download in jpeg format. The original Kodak dcr images (about 8MB) will be available at special request at jsc-earthweb@mail.nasa.gov.

Video imagery for IPY consists of DVCAM files from the video cameras currently onboard ISS (Sony PD 100) and HDTV from a Sony HDW-750a. The HDTV camera will be flown for the first time beginning in early 2007 and its operational parameters for use in orbit are yet to be determined; the capability for downlinking HDTV is also still in development. NASA plans for HDTV to be available for IPY investigators, but the details for its use and video file downlinking will be provided on the CEO website at a later time.

The DVCAM video will be downlinked and recorded on tapes onboard the ISS for later return to Earth. Downlinked video will be transmitted via KU-band radio and the TDRS satellite and placed in a NASA archive within about two to three weeks. In this process, it will be converted from the original DVCAM digital format to analog and then back to digital. Pixel dynamic range will be reduced from one part in 256 (8 bit) to one part in 64 (6 bit) as well as reduced frame rate from 30 to 7.5 frames per second. All recorded video parameters on the original digital tapes such as time stamps and exposure information will be lost on downlinked video. The onboard video will be returned to Earth on subsequent Shuttle missions visiting the ISS with expected delays as long as 6 months. DVCAM clones from the original digital tapes with camera information preserved can be requested. Until distribution details are finalized, contact jsc-earthweb@mail.nasa.gov for all video requests.

4. ISS Subsystems for Earth Observation

The following is a description of the still and video cameras and window characteristics on ISS. Currently, all film-based cameras have been retired due to the logistics of bringing film back to Earth and the subsequent degradation of the film latent image from cosmic rays.

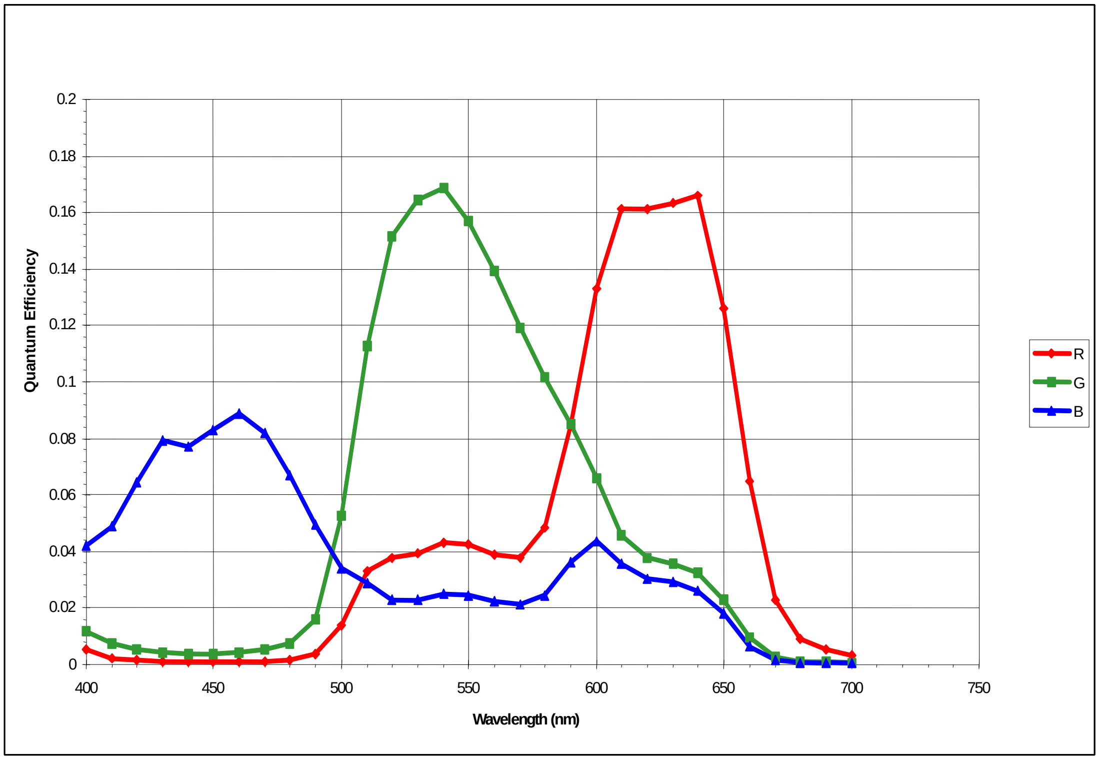
Digital Still Imagery

The current camera equipment used for Earth Observations is the Kodak/Nikon 760 Digital Camera equipped with a number of available Nikon lenses shown in the table below. This camera body is similar to the Nikon F5 film camera with nearly identical operating features and uses the Kodak KAL 6302CE CCD chip. The CCD array has 2008 X 3032 active pixels (6 Mega-pixel) with a physical dimension of 18.48 X 27.65mm (about 75% that of 35mm film). A Bayer color filter and IR blocking filter gives 12 bit per Red-Green-Blue (RGB) channel of color. The pixels are 9 micrometers square and are typically the limiting resolution from the camera system for Earth imagery with any of the lenses (the diffraction limited airy disk is typically smaller than the pixel dimensions). The ISO setting for the CCD array gain is 20 to 400 with 100 typically being used for daytime subjects and 400 for night time. The images are all saved in the Kodak native dcr format at about 8 MB each. Camera data including GMT time (in year:month:day, hour:min:sec format, accurate to about 10 seconds), lens focal length, exposure, and more, is saved as meta data with each image. The capability to record 20 second audio wave files with each image is available. The longest exposure time allowed by the software is 59 seconds however 30 seconds is about the longest useful exposure time due to detector noise. In-camera, auto dark current subtraction for long exposures is possible. Collecting dark current and flat field exposures are also possible for subsequent image processing.

	Field of View with Nikon/Kodak 760 body (degrees)		
Nikon lens	**Horizontal**	**Vertical**	**Diagonal**
14 mm f2.8	89	67	100
16 mm f2.8 fisheye	123	82	148
28 mm f1.4 (aspheric)	52.5	36.5	61.5
50 mm f1.4	31	20	36
58 mm f1.2 (aspheric)	27	18	32
85 mm f1.4	18.5	12.5	22
180 mm f2.8	9	6	10.5
400 mm f2.8	4	2.5	5
800 mm f5.6 (2X extender on 400 mm)	2	1.3	2.5

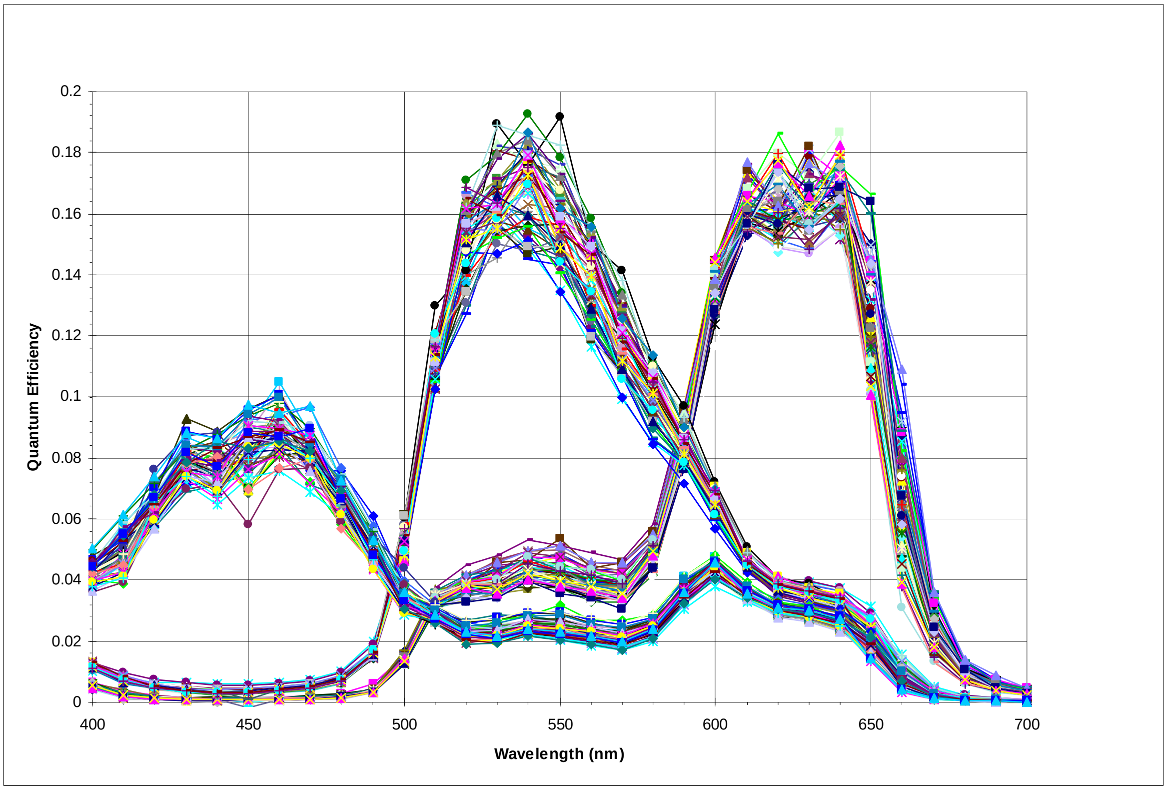
Kodak/Nikon 760 camera-lens field of view (degrees). The camera-lens system field of views are typically less than the ISS window field of view (see section on windows).

The Kodak/Nikon 760 digital camera body has been well characterized for quantum efficiency (QE), however, the cameras on orbit have not been individually calibrated, thus, their individual calibrated response is only known within the confines of the average production QE. Shown below are average production quantum efficiency curves for the 760 camera body (no lens) with Bayer RGB color and IR blocking filters. The QE RGB curves are averaged from 174 different chips from 6 separate production runs.



Average Quantum Efficiency (QE) curves for the Kodak/Nikon 760 camera body using the Kodak KAL 6303CE chip with Bayer RGB color and IR blocking filters for 174 different chips from 6 separate production runs (data courtesy Kodak).

The effect of chip to chip variation in quantum efficiency for production Kodak/Nikon 760 cameras is shown below where QE curves for 174 different chips from 6 separate production runs are superimposed and illustrates the possible range in chip to chip variation that can be expected by not having a specific calibration for a camera body.



Superimposed Quantum Efficiency (QE) curves for 174 different Kodak/Nikon camera backs from 6 different production runs using the Kodak KAL 6303CE chip with Bayer RGB color and IR blocking filters (data courtesy Kodak).

The CCD arrays degrade with orbit time with each camera back being replaced about once a year. At the end of a year there are a significant number of accumulated CCD array defects (from cosmic ray damage), however they typically are not noticable in daytime exposures. Dark current and flat field exposures can effectively remove many of the chip-lens defects in ground-based image processing for nighttime and low light level images.

Video Imagery

Video from the ISS is collected with a Sony PD 100 digital video camera in DVCAM format that can record 40 minutes per miniDV tape cassette. The color CCD array is ¼", 640 X 480 square pixels with a 4.3 to 51.6mm f1.6 zoom lens. A 0.7X wide angle conversion lens is usually mounted over the standard lens giving effective focal lengths of 3 to 36mm and is readily removed if needed. Field of views are shown in the table below. Date and GMT time along with exposure information is recorded on the video tapes. The GMT is typically kept within about 30 seconds of actual. To reduce the number of returned tapes, some video-to-video editing is done on orbit using a firewire connection between two PD100 cameras. The on-board tapes as returned to Earth represent at worst, a second generation clone. From the returned tapes, a master clone set is made from which all further requested copies are made, thus, a requested video scene will be the fourth generation digital clone. Such a copy is practically indistinguishable from the original.

Field of View, Degrees			
Sony PD-100 Video Camera	Horizontal	Vertical	Diagonal
4.3 – 5.16mm zoom (standard lens) 3 – 36mm (with wide angle lens)	61 – 5.6 80 – 8	48 – 4.2 65 – 6	73 – 7 93 – 10

An HDTV Sony HDW-750a video camera will be on ISS in early 2007 with the capability to downlink HDTV. The details of this system will be available when it becomes operational.

It is important to point out that ISS crew members have experienced rather limited success using video to observe low light level subjects like aurora. It is anticipated that the Sony HDW-750a will not perform well with aurora either. Polar mesospheric clouds have been shown to yield outstanding video with the PD 100 and should be a good subject for the HDTV camera.

Crew Time

The crew will make a best effort to collect the requested images for IPY. The crew workday uses Greenwich Mean Time (GMT) where the normal crew work day starts at 07:00 GMT and goes until 19:00 GMT. No official crew time is scheduled for Earth observations, however, the crew uses off hours and break time to collect Earth imagery. A daily uplink list of targets provided by CEO is used as a guide for this activity and are listed for 24 hour periods realizing that the crew may be asleep or tasked with work duties during any particular opportunity. This uplink list will be optimized for Earth targets significant to IPY including specific requests from IPY researchers. Due to the operational demands of running ISS, the effort spent for IPY imagery will be on a time available basis. For any given orbital pass, the crew may not be able to stop their programmatic tasking to collect images for IPY. It is not unusual though, for at least one crew member to pause for a moment and collect images at specific times or orbital positions, particularly if there is some unique observation to be made. During off hours, there is a high probability of acquiring specific site imagery. It is important to realize that an image request may not be collected at a specified moment in time, but over some period of days, the probability of collecting specific IPY images will be high.

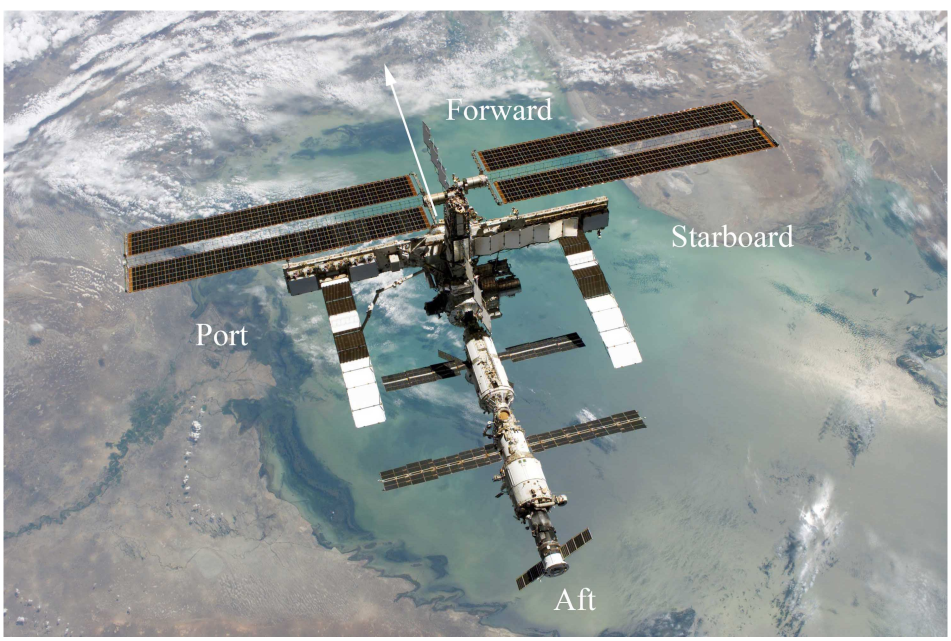
Historically, ISS crews have been good at filling most of the CEO target requests in spite of rather heavy work tasking. This demonstrates the crew's sustained and keen interest in collecting Earth observation imagery. ISS crews on previous expeditions have collected over 50,000 images during a single six month period demonstrating the magnitude of effort and interest in participating in CEO and it is expected that there will be similar enthusiasm for participation in IPY.

5. ISS as an Orbital Platform

Presented below is some basic information on the orbital aspects of interest to IPY researchers for using ISS as an observation platform followed be a description of the windows available for Earth observation.

ISS Coordinate System

The ISS has a coordinate system in which to reference directions relative to its structure. They are ISS-forward, ISS-aft, ISS-port, ISS-starboard, ISS-nadir (deck), and ISS-zenith (overhead). Windows for observation are referenced to their viewing direction based on this reference. The direction of orbital motion for ISS is referred to as "into the velocity vector". The projection of the orbit path onto Earth is called the ground track. Observation points on Earth are referred to as being left, right, or on the ground track.



ISS in August 2005 showing the direction into the velocity vector (white arrow), and forward, aft, port, and starboard directions as referenced to ISS structure. ISS-nadir direction faces Earth and ISS-zenith direction faces space. The ISS-forward direction does not necessarily have to be pointing into the velocity vector as depicted in this image. The attitude is LVLH (see below).

ISS Attitudes

The orientation ISS maintains throughout its orbit in relationship to Earth (or the Sun) is referred to as attitude. The ISS flies two basic attitudes; one where the same side of ISS remains pointed towards the Sun, and one where the same side remains pointed towards the Earth. Note that the side in question for either of these attitudes could be any choice defined by the ISS coordinate system and that the direction of the velocity vector referenced to the ISS structure may vary as the ISS position moves around in its orbit.

When the same side of ISS remains pointed towards the Sun throughout its orbit, then it is referred to as XPOP for X-Axis Perpendicular to Orbital Plane. This attitude is one form of a solar inertial attitude where the orientation of ISS remained fixed in relationship to the Sun as it orbits the Earth. This attitude is used because it maintains solar panels pointing towards the Sun without the need for gross solar tracking and is the attitude of choice during ISS construction. A solar inertial attitude like XPOP differs from a stellar inertial attitude (orientation held fixed with respect to the stars) by about one degree of rotation per day. With an XPOP attitude, any given side or window of ISS will alternate between views of Earth and of space over the period of one orbit or 90 minutes.

When the same side of ISS remains pointed towards the Earth throughout its orbit, then it is referred to as LVLH for Local Vertical Local Horizontal. This attitude is the superposition of a solar inertial attitude with one rotation of ISS about its center of mass every orbit (about 90 minutes) so that the same side of ISS remains pointed towards Earth at all times. This attitude gives the lowest levels of residual acceleration (the best microgravity) and allows for consistent Earth observation views. LVLH will be the standard attitude after the ISS truss construction is completed with ISS-nadir pointing towards Earth and ISS-forward pointing nearly into the velocity vector. The window locations on ISS are optimized for this attitude.

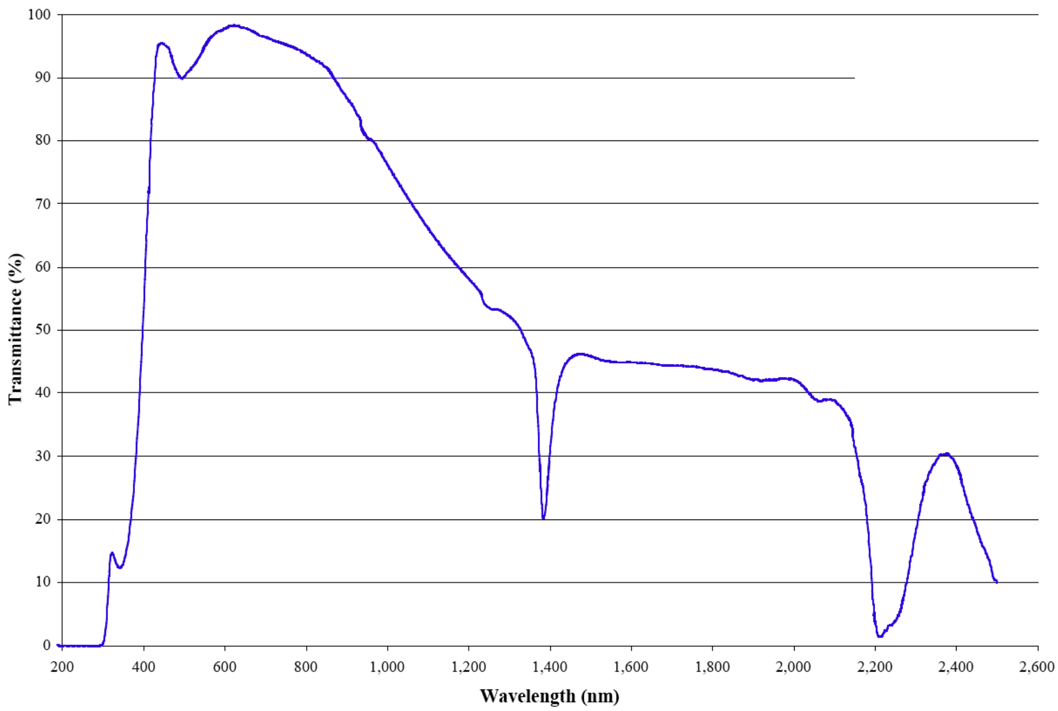
While the space station is under construction, XPOP attitude is flown most of the time. Only for periods of about a week at a time during the docking of a visiting vehicle or for re-boost does ISS fly LVLH. After the main truss activation, probably in 2007-2008, the ISS will fly LVLH as the nominal attitude. During IPY, it is anticipated that ISS will be flying with XPOP attitude about half of the time. In spite of the fact that XPOP does not offer continuous Earth views, it does offer spectacular oblique views every orbit near the day-night terminator in polar regions. ISS crews develop an intuitive skill at determining which windows are best for any given observation.

Windows

Using the ISS reference frame, the windows available for routine Earth observations are located on ISS-nadir (deck), ISS-port (left), and ISS-starboard (right) directions. Depending on ISS orbital attitude, these three viewing directions offer different vantages of Earth. For LVLH attitudes, ISS-nadir windows look directly down at Earth throughout the entire orbit period while the ISS-port and ISS-starboard windows give oblique horizon views. For XPOP attitudes, all windows have a continuously varying view depending on the orbital position. At orbital noon, where the sun angle is nearest to ISS-zenith (orbital noon is located half way between night-day and day-night terminators), the ISS-nadir windows have a nadir view of Earth. At orbital midnight, the ISS-nadir windows look away from Earth into space with Earth being completely out of the field of view. At orbit terminators, ISS-nadir windows offer fantastic Earth oblique views. The ISS-port and ISS-starboard windows cycle through similar views but shifted 90 degrees in orbital position (at orbital midnight, ISS-nadir windows view space while ISS-port and ISS-starboard windows have night time Earth oblique views).

ISS-nadir viewing windows are located in the US LAB module and in the Russian Service module. ISS-port and ISS-starboard windows are located in the Russian Service, and Airlock modules, and in the docked Soyuz spacecraft. There are a number of other small windows however, these are designed for engineering observations and either have optical figure insufficient for photography or are kept shuttered to keep direct rays of sunlight from entering the cabin.

The US Lab has one large ISS-nadir window designed for scientific Earth observations, consisting of two pressure panes, one external debris pane, and one internal scratch pane. The window has a clear aperture of 50.8 cm with a total thickness from outer debris to inner scratch panes of 15.6 cm. There is an external shutter to protect the outer debris pane from orbital debris and from the deposition of outgassing vapors. The shutter is kept closed except during use. The useful full angle field of view is near 135 degrees when using hand held cameras at oblique angles. Both the debris and scratch panes are designed to be replaceable and offer protection for the pressure panes. The pressure panes are AR coated fused silica, 31.8 mm thick. The external debris pane is AR coated fused silica 9.4 mm thick. All three of these panes together give a transmission in the visible above 90% as shown in the transmission plot below.



Transmission in percent (%) versus wavelength in nanometers (nm) for the US Lab window consisting of two coated pressure panes and one coated external debris pane (internal scratch pane removed).

The combined optical figure for these three panes is shown in the table below as a function of the aperture (sub-window diameter) used for the optical measurement. The aperture figures are an average over multiple different regions taken over the full window diameter. For the diameter of most camera lenses, the optical figure is between 1/57 and 1/24 wave.

Aperture (cm)	Wave
5	1/57
10	1/24
20	1/10
30	1/6
45	1/3.5

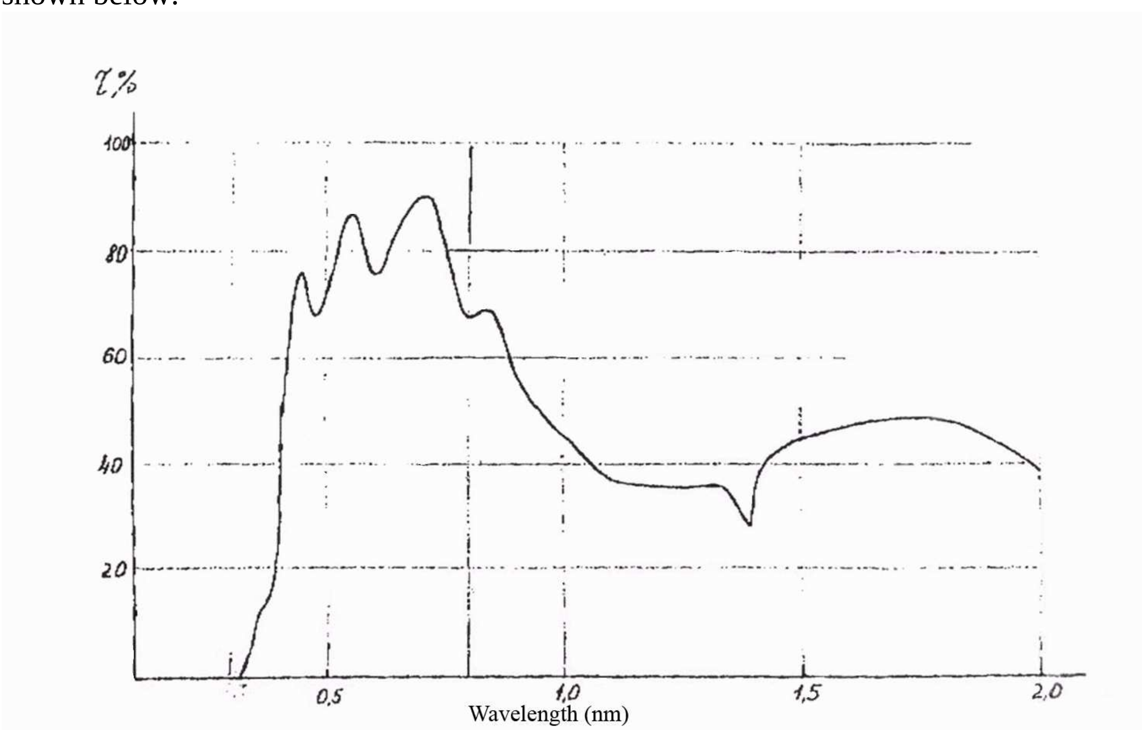
Lab window optical figure for the debris and two pressure panes as a function of aperture diameter. Figures are averaged over multiple apertures within the full window diameter.

The internal scratch pane, intended to be a temporary measure until the Window Observational Research Facility (WORF) is installed, is made from borosilicate glass

11.4 mm thick, has an Indium-Tin oxide plated electrical resistor heater on the inner surface (to prevent water vapor condensation), and an outer (near crew) coating of polycarbonate (to prevent liberation of glass shards if broken). The internal scratch pane reduces the window transmission and optical figure to some degree, however, for Earth observations in the visible spectrum using standard ISS cameras, it does not seriously degrade the resulting images. Nonetheless, past experience indicates that if photography is acquired with the 180, the 400, or the 800 mm telephoto lenses, it is best to use the Russian 22.8 cm window described below; the Lab window works exceptionally well with wide angle lenses.

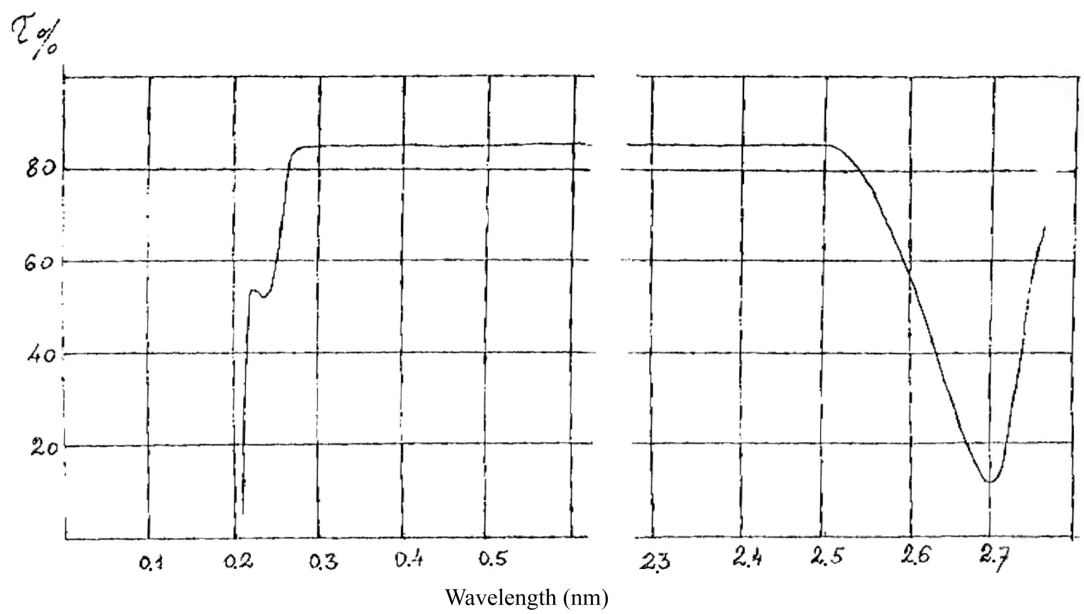
The WORF facility will be installed over the inside of the window and offers protection of the pressure panes so that the inner scratch pane can be permanently removed. The window with WORF allows the optimal configuration for scientific observations with only the three highly transmissive panes with exceptional optical figure. The WORF facility is built and awaiting a planned launch in 2008, so for much of IPY the Lab window will have the internal scratch pane in place.

There are six ISS-nadir viewing windows in the Russian Service module accessible for Earth observation (there are several more that are kept shuttered for special operations and not available for routine Earth observations). Five of the windows consist of two fused silica pressure panes (no debris or scratch panes) 14 mm thick with AR coatings that include an ultraviolet blocking filter so that they offer safe optical transmission for crew exposure. These windows have 22.8 cm of clear aperture and have about 5 cm in outer surface to inner surface separation. The useful full angle field of view is about 70 degrees. These windows have a transmission of above 75% from 400 to 800 nm as shown below.



Optical transmission in percent (%) versus wavelength in nanometers (nm) for the two-paned, coated 22.8 cm diameter Russian windows in the Service and Airlock modules (data courtesy of Energia).

The optical figure for both panes together is given as 2.24 arc seconds resolution over any 60 mm diameter area (the diffraction limit is 2.3 over 60 mm). The sixth window has two uncoated fused silica pressure panes about 37 mm thick with 42.6 cm of clear aperture and about 8 cm in outer surface to inner surface separation. The optical figure is given as 2.00 arc seconds of resolution over any 60 mm diameter area. The full angle field of view is about 100 degrees. This large window is optimized for work in the ultraviolet with the transmission shown below which is at 85% across the visible spectrum. An external shutter for this window is kept closed unless in use to prevent possible eye and skin damage. Protective measures for the crew are required when this window shutter is opened. There is an optional internal filter-scratch pane that can be used to make a safer window for the crew, at some expense of optical figure.



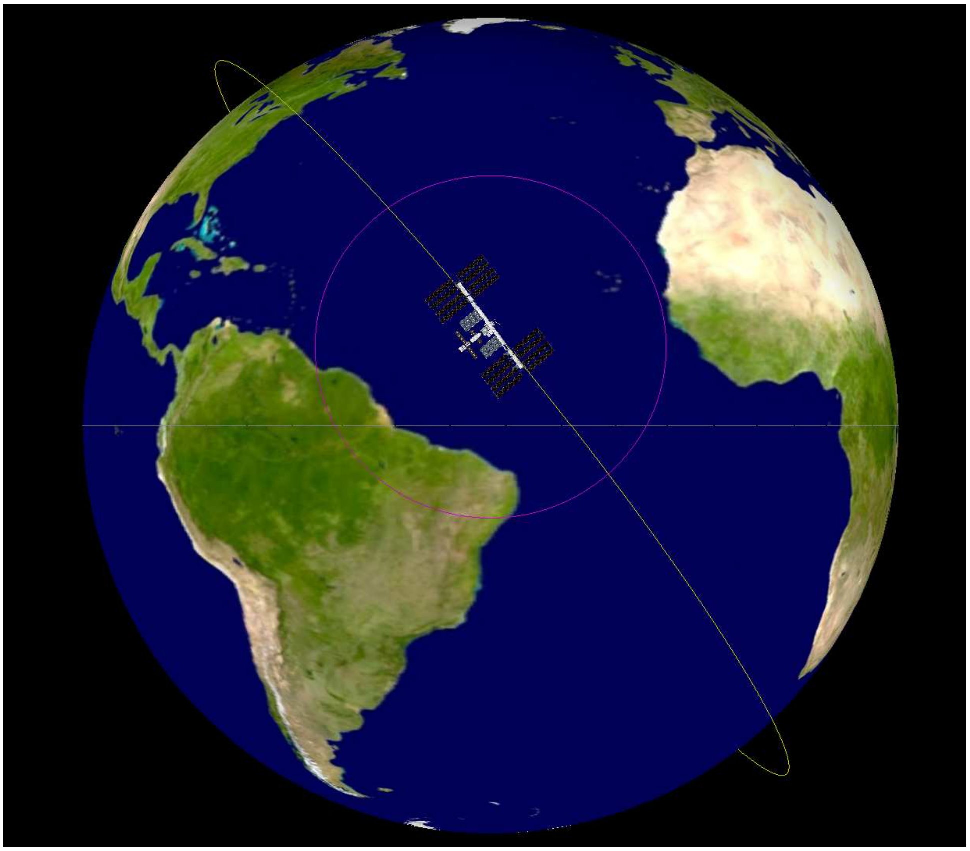
Optical transmission in percent (%) versus wavelength in nanometers (nm) for the two-paned, uncoated 42.6 cm diameter window in the Russian Service module (data courtesy of Energia).

There is one ISS-port and one ISS-starboard window in the Russian Service module, located in each crew sleep station, with the same dimensions and construction of the smaller ISS-nadir windows described above. There are ISS-port and ISS-starboard windows located in the Russian Airlock module. These windows are not perpendicular to the ISS-port and starboard directions but are instead, are on a 45 degree angled plane. This allows for views not only in the port and starboard directions, but also in the forward and aft directions. These windows are the same dimensions and construction as the smaller ISS-nadir windows described above. The Soyuz spacecraft has two windows pointing in the general direction of ISS-port and ISS-starboard, are the same dimensions as the smaller windows above except they have an additional external thermal pane.

All windows on a spacecraft degrade with time. The external surface becomes coated with a thin film-like layer from external spacecraft materials slowly degassing (driven from reactions with solar ultraviolet). Reaction control thrusters, both from ISS and from visiting vehicles, send molecular vapor plumes towards the windows. Micro-meteors impact the windows on occasion and leave star-like pockmarks. Keeping the external shutters closed slows down these types of degradations but over time, these defects will accumulate. The internal surface, no matter how much care is taken by the crew, also accumulates some scratches. Smudges, finger prints (and nose prints) are removed using a cleaning kit. The optical surfaces between the two pressure panes will slowly accumulate a fine dust layer of unknown origin. Due to these effects, the optical transmission of the windows is expected to change from that measured on the ground prior to launch. In the future, the ISS will carry an instrument capable of measuring window transmission is slated to eventually be on orbit.

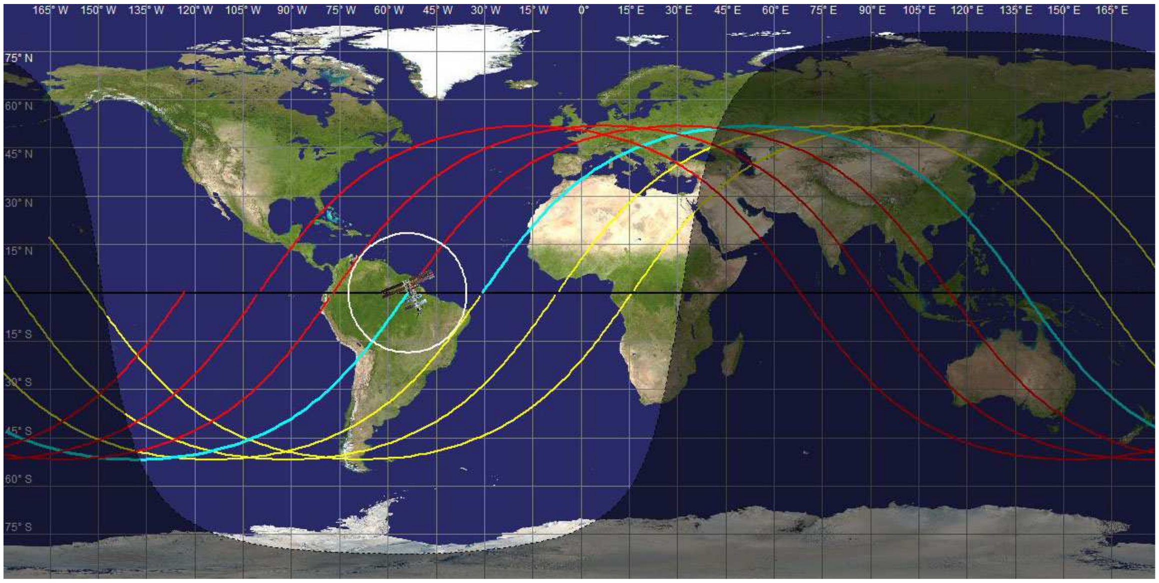
ISS Orbit, Ground Track, and Earth Horizon Circle

The orbit of ISS is essentially circular where the apogee and perigee differ by only a few kilometers. Nominal altitude is designed to be about 400 km. Ninety minutes is a good approximation for the orbital period, giving about 16 orbits every day, although the actual times vary from about 88 to 93 minutes depending on the specific altitude. The orbital inclination is 51.6 degrees which means ISS crosses the equator at 51.6 degrees either ascending (moving from south to north) or descending (moving from north to south). Another consequence of a 51.6 degree inclination is that it’s northern most and southern most point over Earth during orbit is 51.6 degrees in latitude.



Globe view of ISS moving from north to south near the equator where the orbit path is shown in yellow crossing the equator (white line) at an angle of 51.6 degrees. The northern and southern most points in the orbit are also at north and south latitudes of 51.6 degrees. The visual Earth horizon circle is shown in purple centered on ISS and has a diameter about 40 degrees of latitude for an altitude of 400 km.

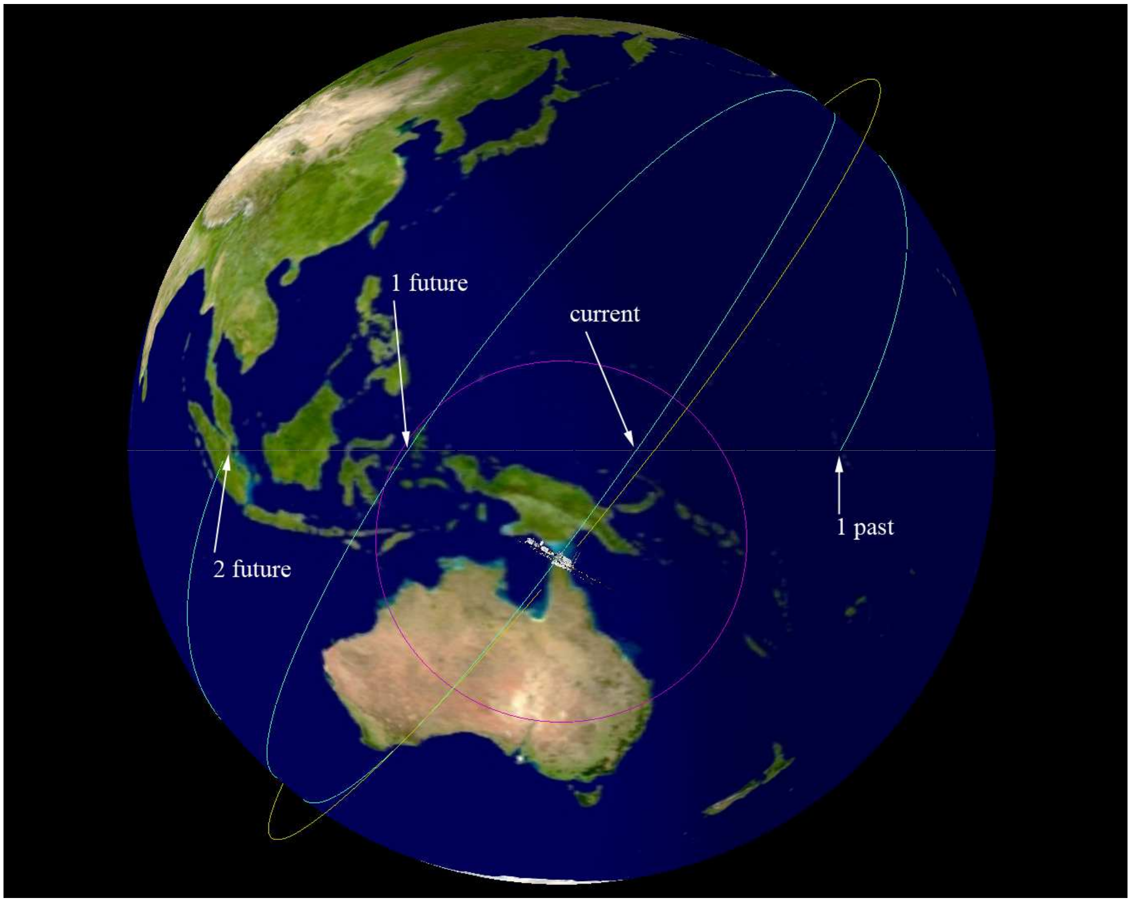
From the ISS at 400 km altitudes, the visual horizon circle has a diameter of about 40 degrees of latitude (also equal to 40 degrees of equatorial longitude) or about 4400 km diameter as shown in the PlateCaree projection below and the previous globe view. This calculation is validated by crews that have noted seeing both the west and east coasts of Australia when ISS is centered over the continent. Due to atmospheric distortion and the extreme obliqueness near the horizon, only simple definitions like the distinction of land versus water can be delineated at these extremes. For Earth imagery of ground sites without gross distortion, the horizon circle diameter is closer to 20 degrees of latitude or 2200 km diameter.



PlateCaree Earth projection of ISS orbit paths showing day-night shadow, current orbit (just completed) in blue, past orbits in yellow, and future orbits in red. Note that in this projection, the day-night shadow and orbit paths take on a curved form. Each subsequent orbit is shifted westward by 22.8 degrees of longitude. The visual Earth horizon circle is shown in white centered on ISS and has a diameter about 40 degrees of latitude for an altitude of 400 km.

Of particular interest for polar observations, at north and south latitudes of 51.6 degrees, the visual horizon circle of 4400 km diameter will translate into about 64 degrees of longitude and range from 31 to 71 degrees of latitude. For observations of upper atmospheric phenomena such as aurora or polar mesospheric clouds at altitudes near 100 km, the visual horizon circle is extended beyond that of the geometric Earth horizon. When an astronaut aboard the ISS at 400 km observes upper atmospheric phenomenon at 100 km in altitude, the diameter of the visual horizon circle is near 60 degrees of latitude. Thus, when the ISS is at the top or bottom of its orbit at 51.6 degrees latitude, crew members can observe upper atmospheric phenomenon up to latitudes of 80 degrees.

Due to the earth's rotation, every time the ISS completes one 90 minute orbit the spot that was directly below during the prior orbit is shifted 22.5 degrees westward in longitude. In addition to this shift, there is a small westward precession of the orbit, called nodal regression, at about 0.3 degrees per orbit or 5 degrees per 24 hours in longitude (this is approximate for ISS; the actual value is near 4.46 degrees per 24 hours; nodal regression depends on orbit eccentricity, altitude and inclination). Thus, the westward shift is about 22.8 degrees per orbit or 365 degrees per day. This effect is illustrated on the PlateCaree map projection above and on the globe view below.



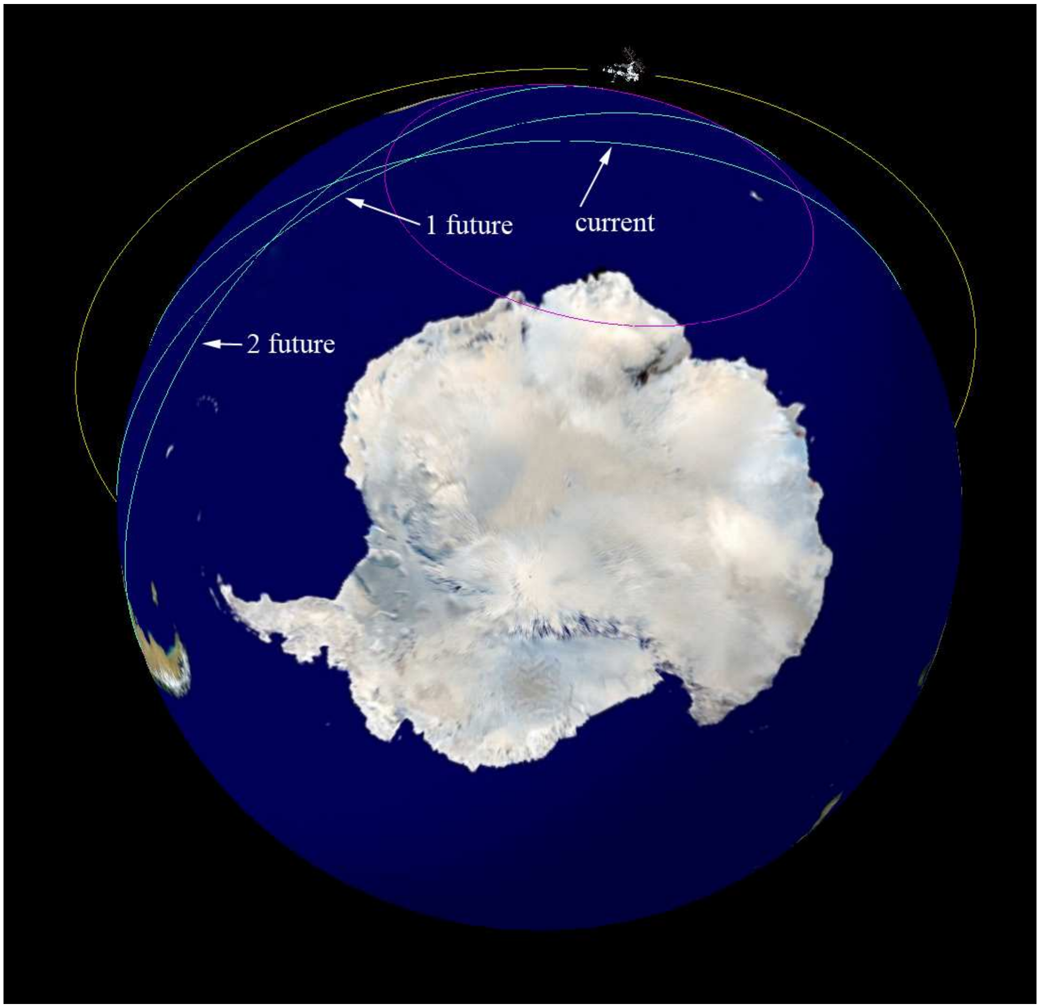
Globe view of ISS moving from south to north near the equator where the orbit path is shown in yellow crossing the equator (white line) at an angle of 51.6 degrees. The ground track is shown in blue beginning for 1-past orbit, current orbit, and 1&2-future orbits showing the 22.8 degree westward shift in longitude. The visual Earth horizon circle is shown in purple centered on ISS and has a diameter about 40 degrees of latitude for an altitude of 400 km.

Orbital Implications to Earth Observations

The implications of Earth rotation and nodal regression are important for Earth observations. There are the pass to pass effects every 90 minutes for a given day caused by the 22.8 degree per orbit shift, which significantly changes the suborbital point for targets near the equator, but not so much at the higher latitudes, and the day to day effects from the approximate 5 degrees per 24 hours westward nodal regression. An important consideration is the change that occurs from one orbit to the next for viewing a point on the Earth due to the local sun angle (local time of day), allowing relief to be photographed as shadows of clouds and mountains get longer but at the cost of less and less light. These different effects determine how many times in a given day an ISS pass occurs over a ground site and for how many days in a row the passes repeat. Nodal regression also affects the lighting angle and the orbit progression cycling between daytime and nighttime passes.

When a specific ground site has viewing opportunities from ISS, there can be one to three useful sequential passes that day, depending on latitude and how the ground track happens to fall in relationship to the site. Since the orbit shifts westward about 5 degrees per 24 hours, it will take about 72 days to make one full precession around Earth (at 4.46 degrees per 24 hours it takes about 81 days) to return back to this initial position. However, when an orbit shift is equal to 22.8 degrees, the current ground track will repeat itself over a prior ground track (this happens about every 4.5 to 5 days for ISS), thus repeating observation opportunities over a ground site but with progressively earlier and earlier local sun angles.

For observations in polar regions, the northern and southern most orbital points will circumscribe the poles every 24 hours, thus offering daily 360 degree views into the polar regions (lighting conditions will vary from daytime to night time as these points circumscribe the poles). Shown below is an example with three sequential south 51.6 latitude orbit points. The ground tracks have a greater measure of overlap at high and low latitudes so that repeated observations on sequential orbits can be obtained.

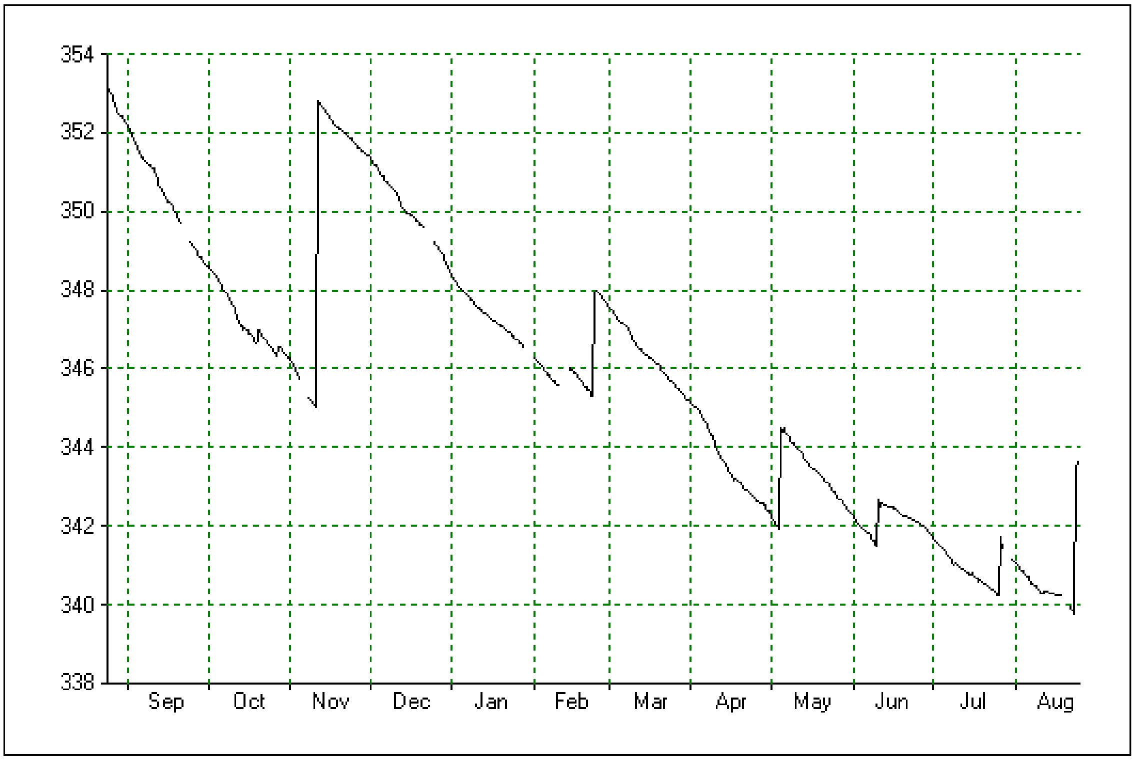


Globe view of ISS at south 51.6 degrees latitude with orbit path in yellow, ground tracks for current and two future passes in blue, and horizon line in purple. The current position at south 51.6 is marked as well as the next two future positions at 51.6 degrees showing the westward movement of the southern most point due to the 22.8 degree shift per orbit. In a 24 hour period, these points circumscribe the poles.

For additional reading, a web-based tutorial on the ISS orbit applied to earth observation can be found at: http://eol.jsc.nasa.gov/orbtutor/page1.htm

Orbital Altitude of ISS and the Prediction of ISS Position

The nominal altitude of ISS is 400 km although for 2005-2006 it has been allowed to drop to about 350 km. Residual atmospheric drag, mainly working on the large surface area solar panels, lowers the altitude by about 80 meters a day (this is the main component force that gives residual accelerations in the 1 to 2 micro-g range). About every 4 to 12 weeks, a re-boost is done where rocket thrusters are used to raise the orbit. Sometimes the altitude is allowed to drop as low as 340 km due to the logistics of visiting vehicles and propellant re-supply. The variations in orbital altitude due to atmospheric drag are readily incorporated into pass prediction calculations. However, it is difficult to accurately model in advance the effects of re-boost on the pass prediction calculations. Reboost results in a step jump in orbital elements thus changing the pass prediction times. A re-boost then impacts Earth observations due to the slight change in orbital period. If a re-boost occurs and the pass predicting software does not include this effect, the predictions may be off by ten minutes or more. Shown below is a plot of ISS orbital altitude during 2005-2006. The orbital altitude dropped to accommodate a series of Shuttle assembly missions. Notice the jump discontinuity in altitude from the re-boosts.



Orbital altitude of ISS in kilometers for Sept 2005 to Aug 2006 (plot courtesy of Heavens-Above website http://www.heavens-above.com/)

Re-boosts are usually planned about a week in advance with a targeted change in altitude but the actual change may be different and not known until after the thrusters are shut down. The major impact on re-boost for Earth observations is the inability to predict accurate ISS passes months in advance. While the general lighting conditions (whether it a daytime or a nighttime pass) can be predicted for a region, accurate time predictions for ISS overpasses of a specific location can be made only a few days before the observation.

There are a number of web-based pass prediction sites available as well as stand alone software programs. A quick web search will reveal many possibilities. It is important to differentiate sites that give visible pass predictions where the ISS passes are filtered for evening and dawn lighting versus pass prediction under any lighting conditions. We provide several links in below.

- To determine when the ISS will have a ground site pass under any lighting condition, try: http://www.amsat.org/amsat-new/tools/predict/

- An inexpensive software satellite prediction program called NOVA can be downloaded for purchase online by searching under NOVA and satellite

- Good sources for ISS current positions, orbital parameters, and pass predictions filtered for visual sightings under evening or morning dark sky conditions can be found on the following websites (The Heavens Above website is reported to update their ISS orbital parameters every 4 hours from NASA website data streams):
    - http://www.heavens-above.com/
    - http://spaceflight.nasa.gov/realdata/tracking/index.html

- For determining when the ISS was near a specific ground site from past ISS imagery found in the archives: NASA provides an calculator for correlating ISS ground position with time for past ISS expeditions: http://eol.jsc.nasa.gov/pos2time/default.htm

- If an image is available with known date and time with position unknown, an ISS time-to-position calculator is available at: http://eol.jsc.nasa.gov/time2pos/default.htm

These orbital predictors are included for investigators to better understand the parameters involved in planning successful observations. CEO will be tracking the daily orbit tracks and ISS observational windows, as described in the Ground Operations section and will determine the best match to an IPY observation request. Again, the IPY investigator does not need to determine the ISS ground tracks, the optimum viewing window, and such, these details have simply been provide for those who want to understand the dynamics of making such observations possible.

Document Revision History:
Started: June 22, 2006
Finished: Sept. 14, 2006
Revised: Sept. 29, 2006 with comments from:

Julie Robinson NASA-JSC OZ
Mike Foale NASA-JSC CB
Cindy Evans NASA-JSC KX